N° d'Enregistrement
au C.N.R.S.
AO 9040

ARTICLE PRINCIPAL

Recouvrant en tout

THESE DE DOCTORAT D'ETAT ES SCIENCES PHYSIQUES

présentée

A L'UNIVERSITE PARIS VI

Par

Jean GUIBERT

pour obtenir

le grade de Docteur ès-Sciences

Sujet de la thèse : " Hydrogène neutre et structure spirale dans la Galaxie M31 ".

Soutenue le 29 octobre 1973 devant la Commission d'Examen composée de :

MM.	*F. NAHON*	*Président*
	J. LEQUEUX	*Examinateurs*
	L. WELIACHEW	
	G. MONNET	
	J. BALDWIN	

N° d'Enregistrement
au C.N.R.S.
AO 9040

ARTICLE PRINCIPAL

Recouvrant en tout

THESE DE DOCTORAT D'ETAT ES SCIENCES PHYSIQUES

présentée

A L'UNIVERSITE PARIS VI

Par

Jean GUIBERT

pour obtenir

le grade de Docteur ès-Sciences

Sujet de la thèse : " Hydrogène neutre et structure spirale dans la Galaxie M31 ".

Soutenue le 29 octobre 1973 devant la Commission d'Examen composée de :

MM.	*F. NAHON*	*Président*
	J. LEQUEUX	*Examinateurs*
	L. WELIACHEW	
	G. MONNET	
	J. BALDWIN	

UNIV.
LEIDEN
BIBL.

1973, *Astron. Astrophys. Suppl.* **12**, 263-276.

A NEUTRAL HYDROGEN SURVEY OF THE ANDROMEDA NEBULA

J. GUIBERT
Département de Radioastronomie
Observatoire de Meudon, France

Received December 12, 1972, revised March 26, 1973

The Neutral Hydrogen in the Andromeda Nebula (M 31) has been investigated with the Nançay transit telescope. The purpose of the survey was to study the neutral hydrogen distribution and dynamics, and correlations between the gas and the main optical features of the galaxy. The resolution was 4′ in right ascension, 25′ in declination, and 12.7 km s^{-1} in velocity. At the distance of M 31, 4′ corresponds to 800 pc, about the width of the spiral arms of the nebula as outlined by the H II regions. This paper presents the characteristics of the antenna pattern and the results of the survey in the form of maps of the H I distribution at constant velocities.

Key words: galaxies – hydrogen

1. INTRODUCTION

The nearby galaxy M 31 has been the object of 21 cm line studies by many authors (see for instance Davies and Gottesman 1970). Because of its large angular extent (5 degrees along the major axis in the radio continuum and 21 cm line domains) and its morphological type (M 31 may be classified as Sb) it is quite suitable for investigation, by means of its neutral hydrogen distribution, of its mass distribution, velocity field and rotation curve, spiral structure and comparison of radio features with optical features. In the latter domain, a great amount of data is available about H II regions, OB star associations and other Population I objects in M 31. Moreover, the Andromeda Nebula is similar to our own Galaxy in many respects and observations of M 31 may allow comparisons with the Milky Way.

The work reported here has been done with the Nançay radiotelescope. Observations were carried out during two periods: August 1968–February 1969, and October 1969–February 1970. At 21 cm wavelength, the antenna beamwidth is 4′ in right ascension and 25′ in declination, at the declination of M 31. The channel width used was 60 kHz (12.7 km s^{-1}). This paper first presents the main features of the antenna beam at 21 cm, then a brief description of the observational procedure, and finally the data obtained in the survey. They appear in the form of constant velocity maps.

Previous studies of neutral hydrogen in M 31 have been made by van de Hulst *et al.* (1957), Burke *et al.* (1963, 1964), Brundage and Kraus (1965), Argyle (1965), Roberts (1966, 1967), Gottesman, Davies and Reddish (1966), and Davies and Gottesman (1970). They are summarized in Table 1 which displays the antenna beam size, the velocity resolution and the extension of the surveyed regions for each study.

The present survey differs from the previous studies in two respects. The signal to noise ratio is the best one, at least in a declination range of width 37′ in the southern part of M 31, and the resolving power of the Nançay telescope in right ascension is 2.5 times greater than the best one appearing in Table 1 (Roberts 1966, 1967). The velocity resolution of 12.7 km s^{-1} is well suited for this angular resolution.

2. THE NANÇAY TELESCOPE BEAM-SHAPE

2.1. The Antenna

The Nançay radiotelescope has been described elsewhere (Blum *et al.* 1963). The feed can be moved in the focal plane, thus permitting tracking of sources during half an hour on both sides of the meridian.

For studies of galaxies of large angular extent such as M 31 or M 33 (Huchtmeier 1972, 1973) a good knowledge of the antenna pattern was needed, particularly in view of model-fitting calculations and discussions about detailed structure.

Two radio-sources, 3C 48 and 3C 123, strong enough and known not to be variable, were chosen as calibrators owing to their proximity in declination to M 31 and M 33. They were observed every day for the determination of the antenna pattern and the calibration of the line receiver. In addition, several other sources, especially at declinations between 30° and 48°, provided information, by means of interpolation, about the main parameters of the antenna at the declination of M 31 (41°).

2.2. Main Features of the Antenna Beam Shape

Up to 15 drift scans on the source 3C 123 could be performed in one day. The extent of the measured antenna pattern was 20^m in right ascension and 4° in declination. The results, averaged over the two observing periods, are shown in figure 1.

2.3. Right Ascension

Figure 1(a) shows the hour angle effect on the beam profile in right ascension. Thirteen drift curves are plotted for hour angles varying from -30^m to $+30^m$. The average beam pattern used in the processing of M 31 line observations has been obtained as a weighted mean of the beam profiles at hour angles -30^m, -10^m, $+10^m$, the weights being the numbers of drift curves obtained on M 31 at each of these three positions. This average beam profile is displayed in figure 1(b). The strongest sidelobe is 4.3% of the main beam.

In view of model-fitting calculations, the adopted beam shape in right ascension has been convolved by a 10 sec wide rectangular window to account for the integration time used for the drift scans on M 31.

2.4. Grating Sidelobes

Due to the periodic structure of the plane reflector which is composed of ten pannels, the Nançay radiotelescope shows far grating sidelobes. They are located about 36′ from the main beam, in accordance with the wavelength used here (21 cm) and the periodicity of the reflector (20 m). Careful examination of drift curves taken with strong calibration sources show that these grating sidelobes never exceed 2%. Their mean contribution, after averaging over several hour angles, is about 1% of the main beam.

2.5. Declination

The observations performed in the declination range of M 31 and M 33 showed that the beam profile in declination was practically insensitive to hour angle. Figure 1(c) represents the beam shape in declination,

up to 70′ to the north and the south of the main beam. Practically no sidelobe can be seen on the south side of the main beam; two successive sidelobes appear on the north side, but the strongest does not exceed 4.2% of the main beam.

3. THE RECEIVER

The correlation receiver in use at Nançay has been described by Blum *et al.* (1966), and by Allen (1969). As mentioned above, M 31 was observed during two periods; the system noise temperature was 150 K and 110 K respectively. The filter bank employed for M 31 comprises 15 filters, of which 13 are 60 kHz (12.7 km s^{-1}) wide at half power. Their shape is nearly rectangular and their central frequencies are spaced by 120 kHz. By tuning the local oscillator, it was possible to provide complete coverage of a spectrum up to 24 channels (300 km s^{-1}) wide, as needed in the central regions of the galaxy. The bank was completed by two broader filters, 600 kHz wide, spaced by 600 kHz from the outermost narrow ones; these two filters provided information on the radio continuum emission; during the data reduction, the radio continuum was subtracted from the observations, thus yielding the line radiation.

4. OBSERVATIONS AND DATA REDUCTION

The observations reported here were made in the form of drift scans. The telescope allowed up to five drift scans on M 31 per day. Each scan extended over 20^m in right ascension ($\pm 10^m$ either side of the major axis), except for the outer declinations for which the extension was only $\pm 6^m$ in R.A.

Owing to the declination of M 31 (41°) and the characteristics of the beam as described above, an integration time of 10 sec (approximately 1′.9) was adopted and the galaxy was scanned at declinations separated by 12′.5. This paper presents observations extending from 2° 20′ south of the centre to 1° 40′ north of the centre.

A noise tube, calibrated every day by means of radio sources as mentioned above, provided a reference signal at the end of each drift scan.

For a system noise temperature of 150 K, a channel width of 60 kHz and an integration time of 10 sec, the rms fluctuation is around 0.3 K. The observations were repeated until a rms noise of 0.16 K was obtained, except for certain declinations, chosen for interesting optical features, for which the rms fluctuation was lowered to 0.08 K. During the first observing period, the beam efficiency was 60%. During the second period, another primary feed was used and the beam efficiency was 50%. These figures have been determined, to better than 10%, from the aperture efficiency and the beam shape. Data obtained during the second period have been corrected to take account of the lower beam efficiency. Thus, antenna temperatures appearing throughout this paper refer to a beam efficiency of 60%, and the highest value observed, 15 K, corresponds to a maximum brightness temperature of 25 K.

5. PRESENTATION OF RESULTS

Figure 2 displays the results of the survey in the form of constant radial velocity maps. There are 45 such maps; they are separated in velocity by 12.7 km s^{-1} (the width of a channel). The velocity ranges from -590 km s^{-1} to -34 km s^{-1}. Two crosses appear on each map: the first, in the upper right corner

represents the half-power beamwidths both in right ascension and in declination, while the second, with equal length arms, indicates the position of the optical centre. The coordinates are for the epoch 1950.0 and the radial velocities are relative to the Sun. To convert these velocities to the local standard of rest, a correction of $+4$ km s^{-1} must be applied. The contours are drawn every 1 K of antenna temperature, except the two lowest contours which corresponds to 0.25 K and 0.5 K. A dashed line has generally been used for the contour at 0.25 K except for declinations where the rms noise was 0.08 K.

ACKNOWLEDGEMENTS

This work would have not been possible without the assistance of the staff at Nançay Observatory, particularly B. Darchy for the maintenance of the receiver, J.P. Drouhin, and Miss O. Franquelin for the programming of the on-line computer. Mrs. F. Foy helped in data reduction. The author is greatly indebted to Dr. W. Huchtmeier for his cooperation during observations, assistance in preparing reduction programs, and many fruitful discussions.

REFERENCES

Allen, R.J.: 1969, *Astron. Astrophys.* **3**, 316.
Argyle, E.: 1965, *Astrophys. J.* **141**, 750
Blum, E.J., Boischot, A., and Lequeux, J.: 1963, *Proc. Instn. Radio Eng. Austr.* **24**, 208.
Blum, E.J., Delannoy, J., Leroux, E., and Weliachew, L.: 1966, *Compt. Rend. Acad. Sci. Paris* **262 B**, 1640.
Brundage, W.D. and Kraus, J.D.: 1965, *Astron. J.* **70**, 669.
Burke, B.F., Turner, K.C., and Tuve, M.A.: 1963, in *Annual Report of the Director,* Department of Terrestrial Magnetism, Carnegie Inst. Washington Year Book, 1962-63, 289.
Burke, B.F., Turner, K.C., and Tuve, M.A.: 1964, in *Annual Report of the Director,* Department of Terrestrial Magnetism, Carnegie Inst. Washington Year Book, 1963-64, 341.
Davies, R.D. and Gottesman, S.T.: 1970, *Monthly Notices Roy. Astron. Soc.* **149**, 237.
Gottesman, S.T., Davies, R.D., and Reddish, V.C.: 1966, *Monthly Notices Roy. Astron. Soc.* **133**, 359.
Huchtmeier, W.: 1972, *Astron. Astrophys. Suppl.* **7**, 397.
Huchtmeier, W.: 1973, *Astron. Astrophys.* **22** no. 1, 91.
Hulst, H.C. van de, Raimond, E., and Woerden, H. van: 1957, *Bull. Astron. Inst. Neth.* **14**, 1.
Roberts, M.S.: 1966, *Astrophys. J.* **144**, 639.
Roberts, M.S.: 1967, H. van Woerden (ed.), *IAU Symposium* no. 31, Academic Press, London and New York, p. 189.

J. Guibert

Observatoire de Meudon
Département de Radioastronomie
F – 92190 Meudon, France

Table 1 Neutral Hydrogen line surveys of the Andromeda Nebula

Authors	Telescope	H.P.B.W.	Velocity Resolution	Extension of the Survey Right Ascension	Declination
van de Hulst et al. 1957	Dwingeloo, 25 m	34'	29 km/s	major axis only	
Burke et al. 1963 1964	Green Bank, 300 ft	10'	2.1 & 10.5 km/s	major and minor axes	
Argyle 1965	D.R.A.O., 25 m	36'	35 km/s	15 min	6°
Roberts 1966	Green Bank, 300 ft	10'	21 km/s	12 min	2°
Gottesman et al. 1966	Jodrell Bank, 250 ft	14' x 18'	42 km/s	south and selected points in the north	
Brundage, Kraus 1966	Ohio State 80 m x 24 m	10' x 38'	21 km/s	30 min	2°30'
Roberts 1967	Green Bank, 300 ft	10'	21 km/s	12 min	4°
Davies, Gottesman 1970	Jodrell Bank, 250 ft	14' x 18'	8.4 km/s	20 min	4°
This work	Nançay, 200 m x 35 m	4' x 25'	12.7 km/s	20 min	4°

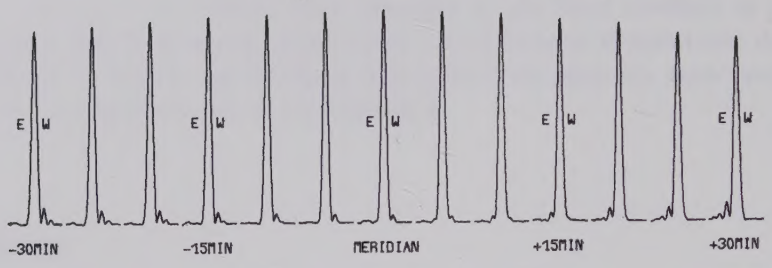

Fig. 1 a

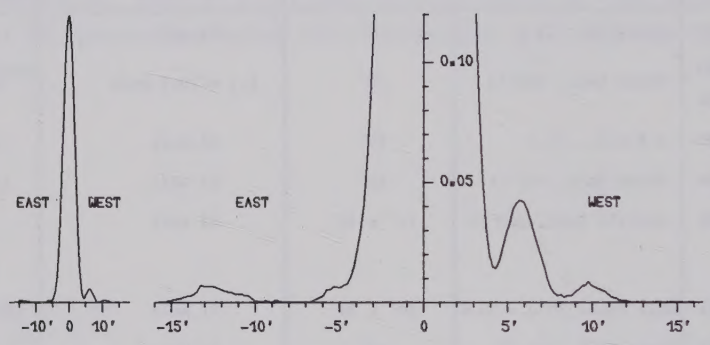

Fig. 1 b

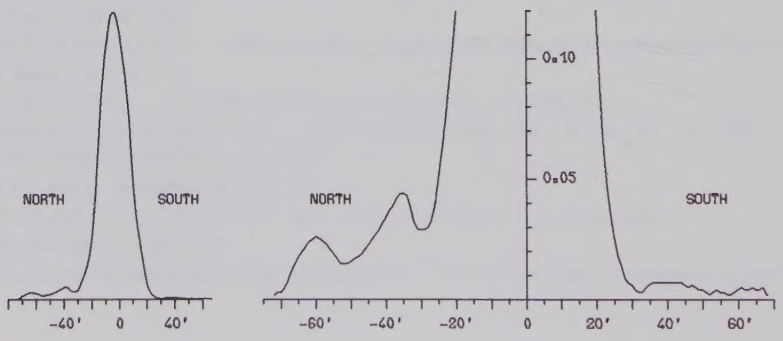

Fig. 1 c

Figure 1 The Nançay Telescope Beam Shapes

a) Right ascension beam profiles obtained during the transit of a reference source for 13 values of the hour angle. For each beam profile, time increases from left to right.

b) Average right ascension beam profile corresponding to M 31 observations. Details of the sidelobes are visible on the right of the figure.

c) Declination beam profile at the declination of M 31 (41°), and details of the sidelobes.

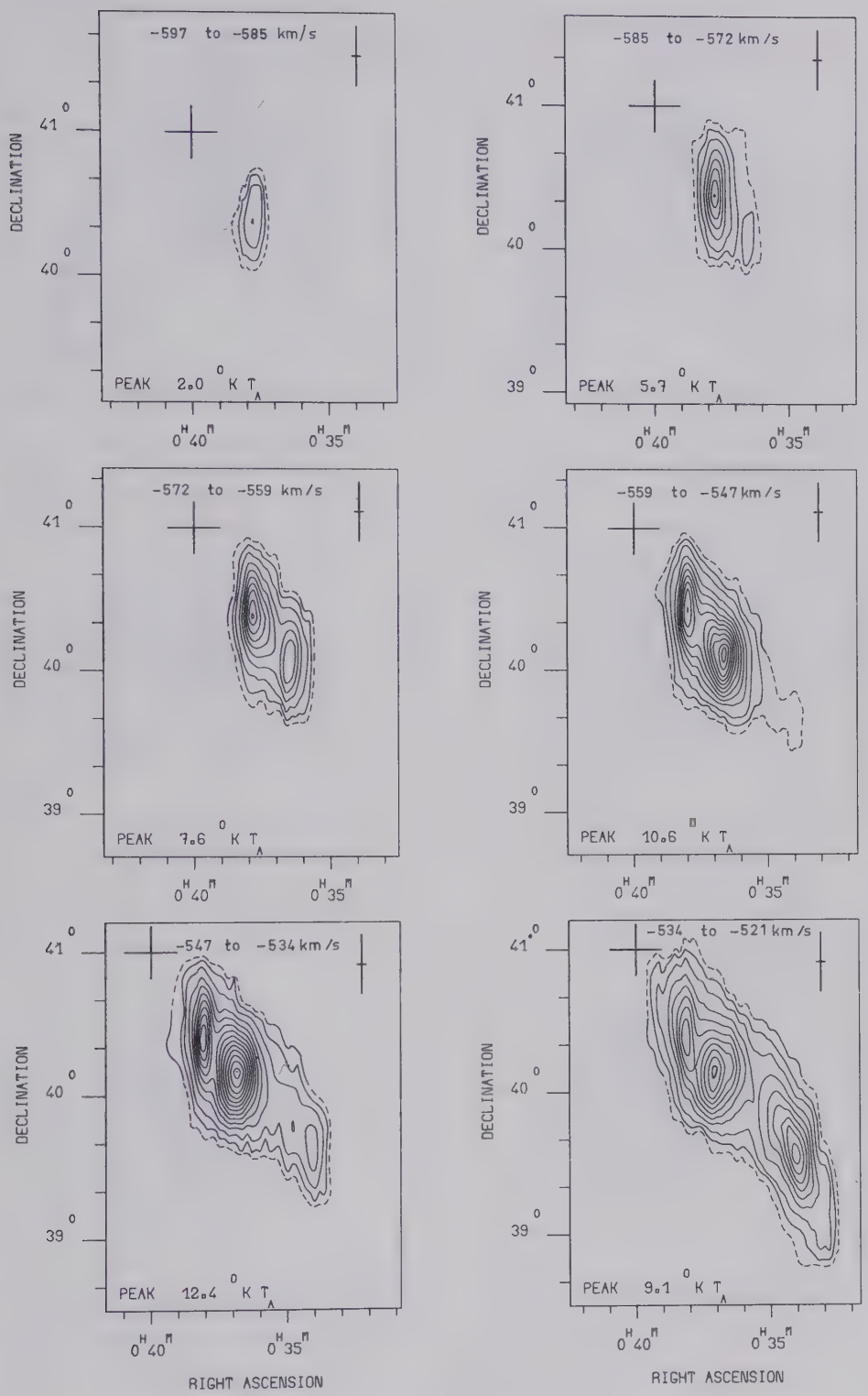

Figure 2 Constant velocity maps

Individual velocity maps of the H I density in M 31. The contours are drawn every 1 K of antenna temperature, except the two lowest which refer to 0.25 and 0.5 K

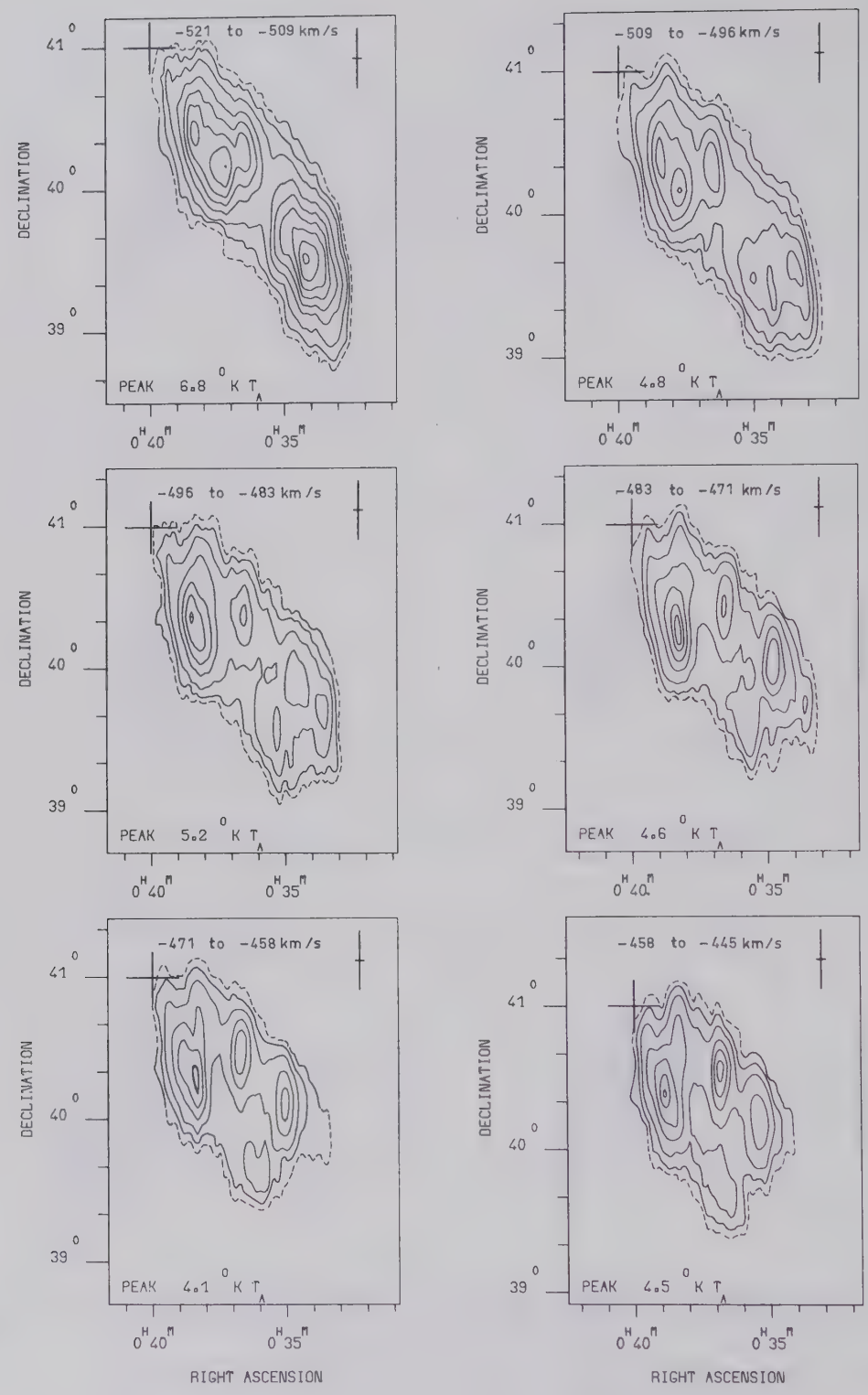

Figure 2 *(continued)*

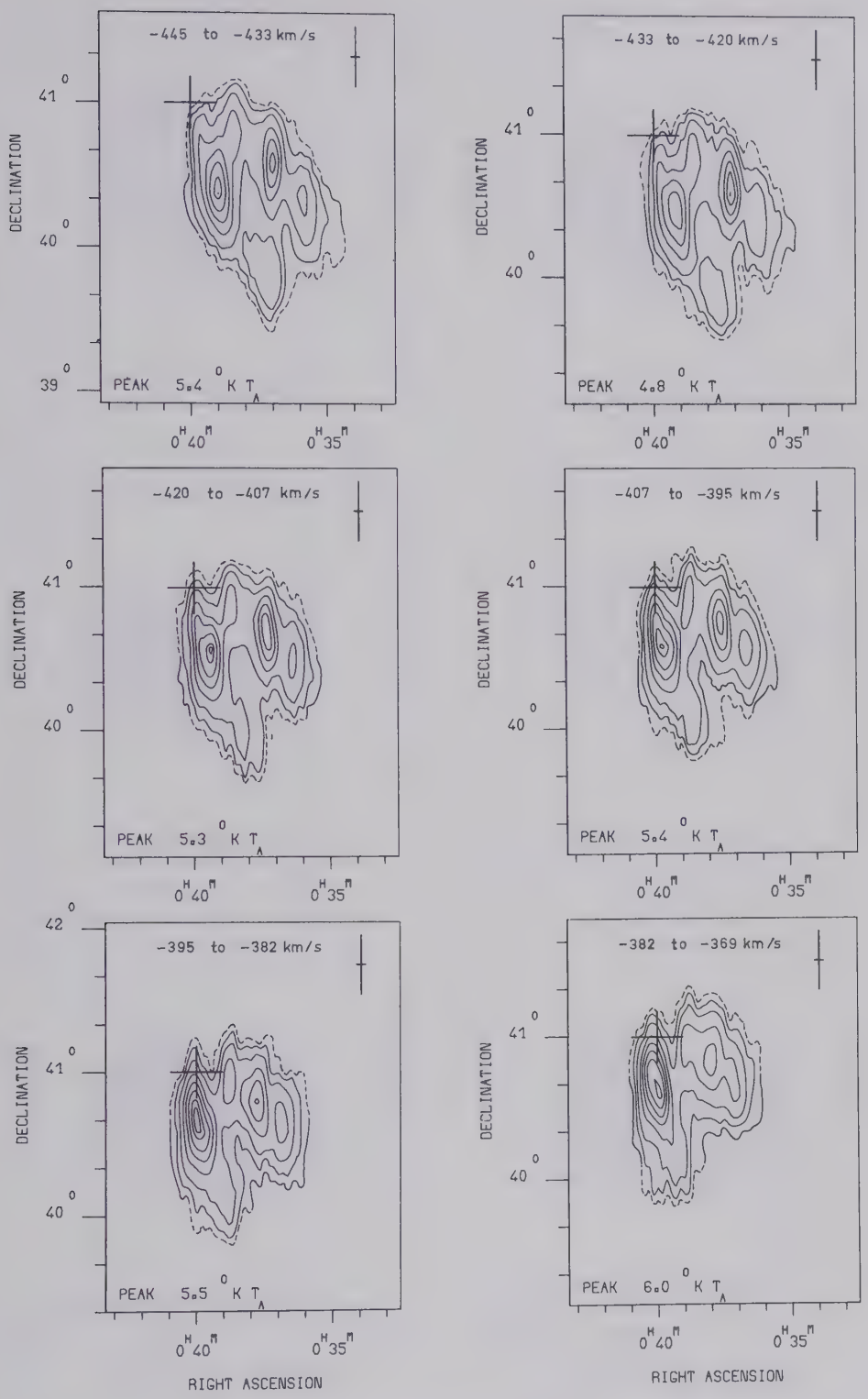

Figure 2 *(continued)*

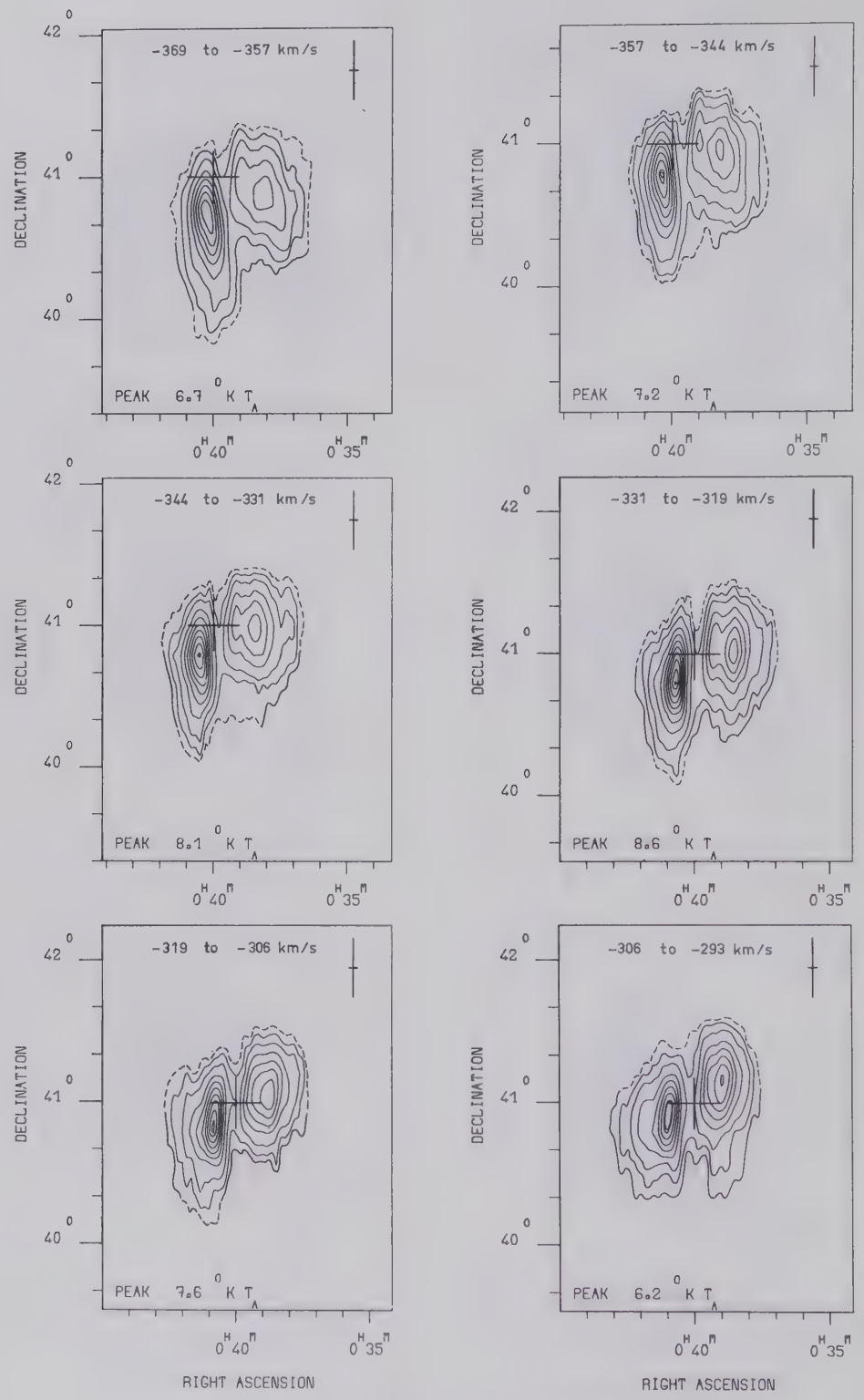

Figure 2 *(continued)*

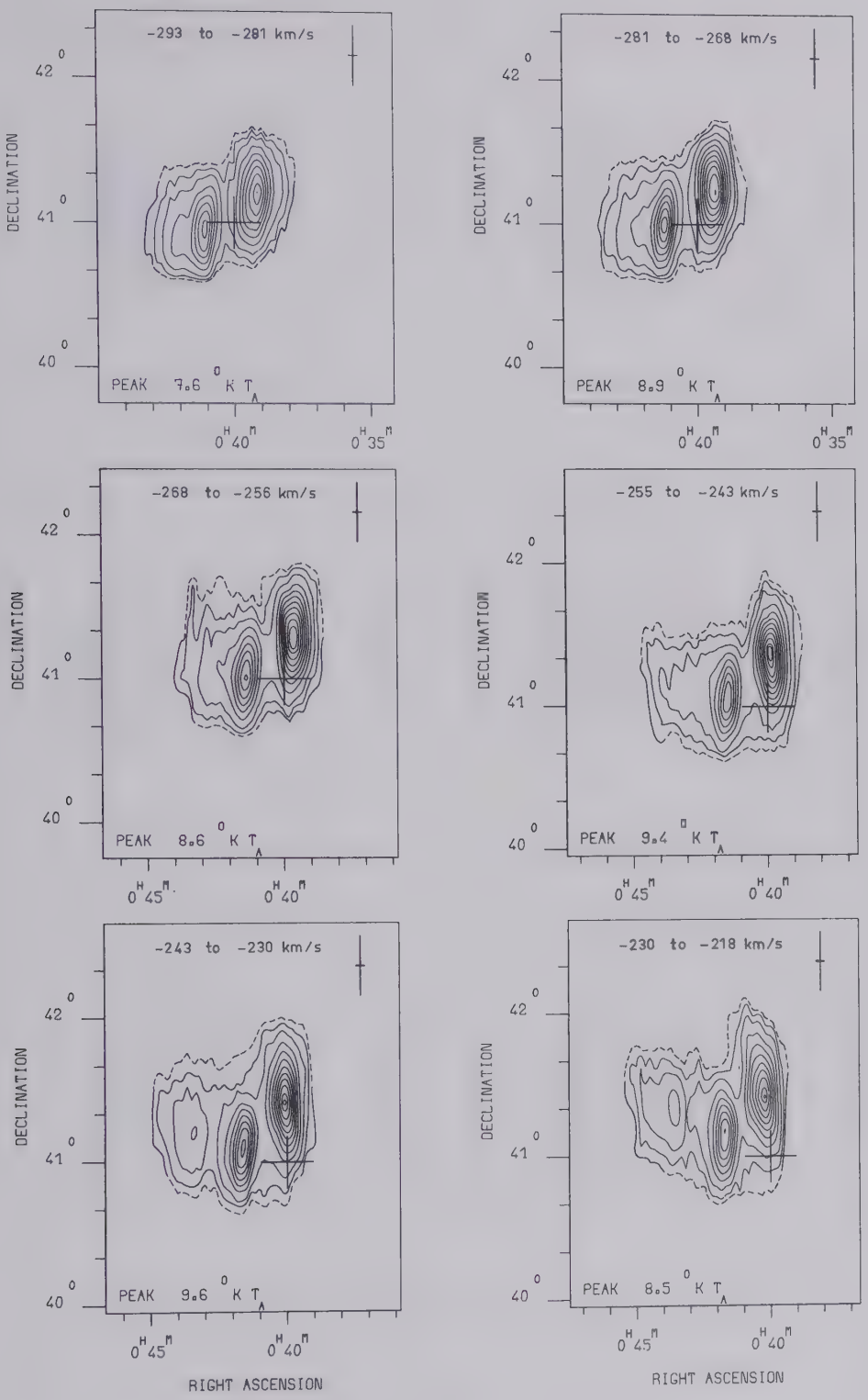

Figure 2 *(continued)*

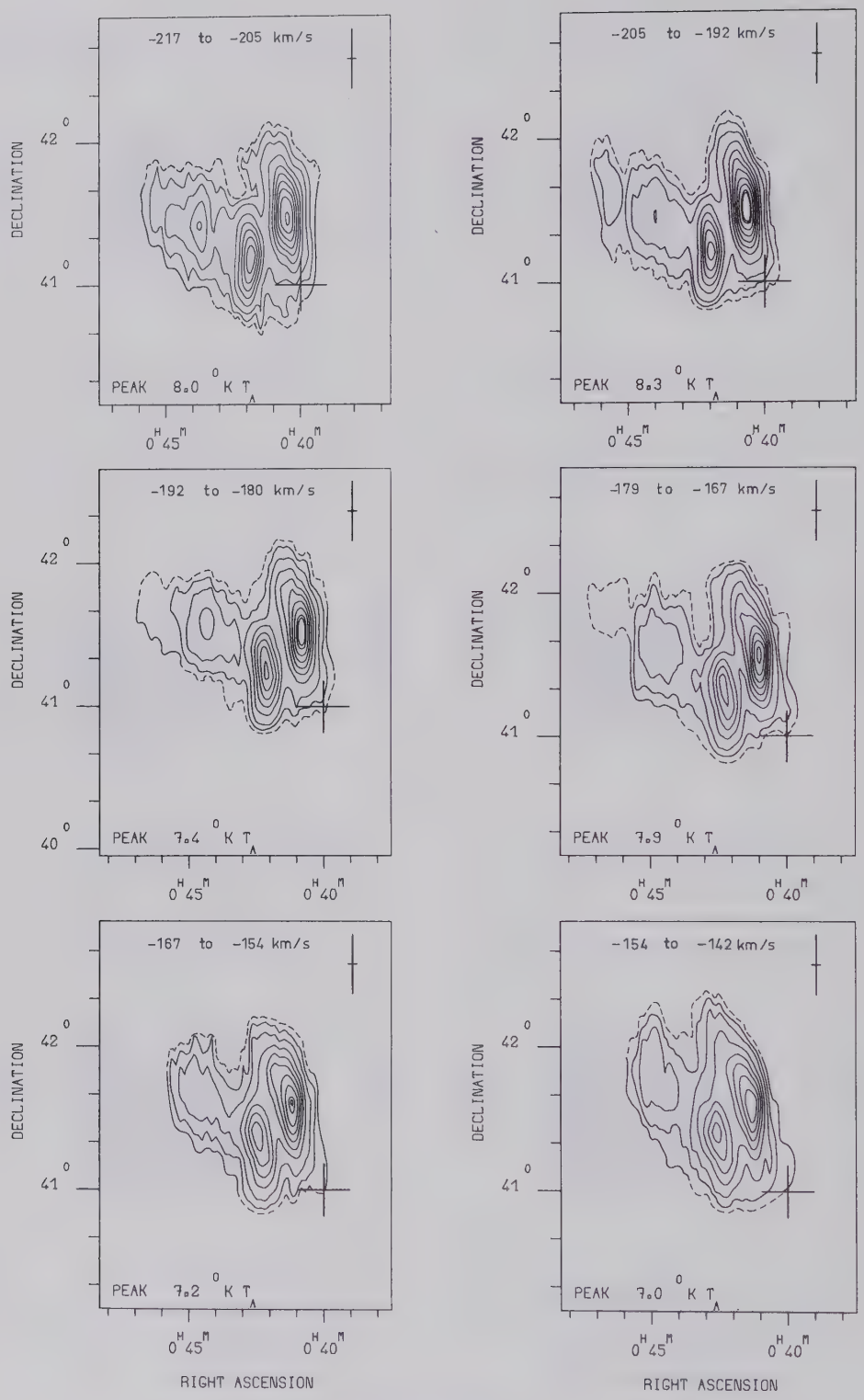

Figure 2 *(continued)*

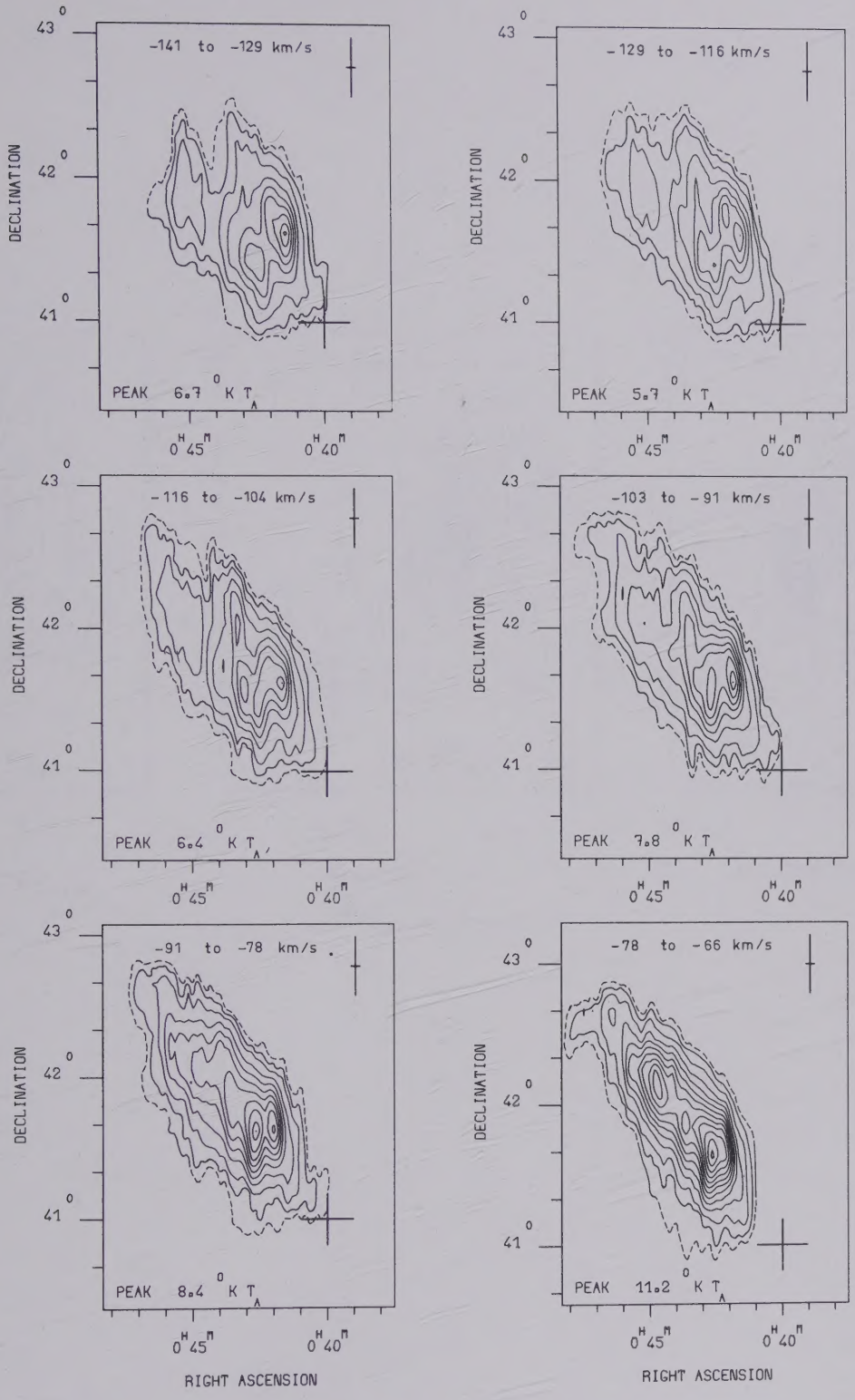

Figure 2 *(continued)*

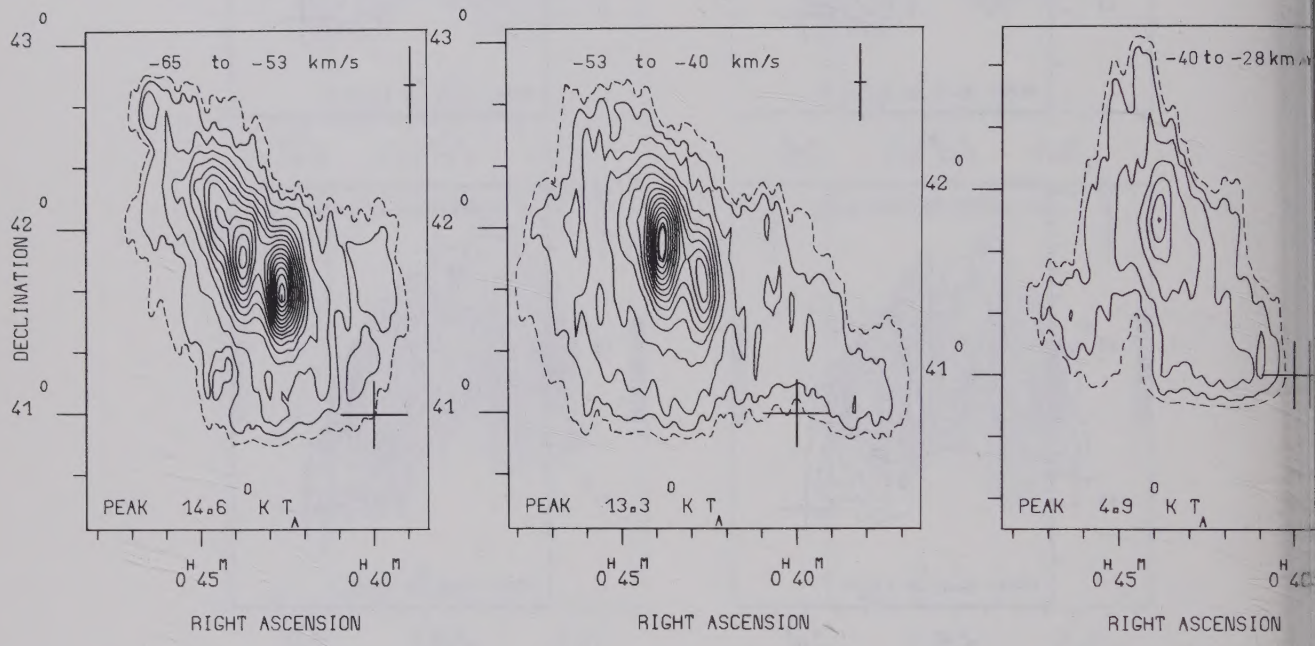

Figure 2 *(continued)*